

# Superconducting Quantum Phase Transitions

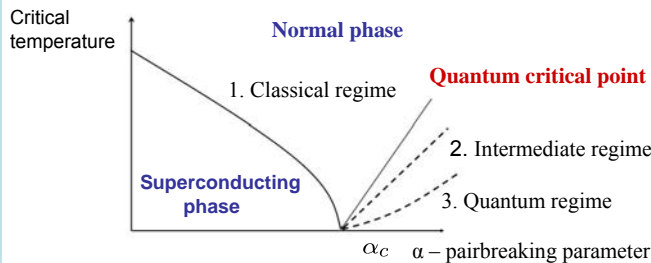
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## Superconducting Quantum critical point

Superconducting quantum phase transition (QPT) is a zero temperature phase transition that occurs when the superconductivity is suppressed due to the presence of pair breaking effects. The zero temperature transition point is often called the quantum critical point (QCP).

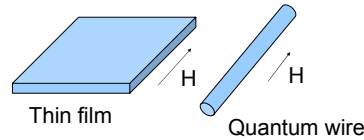


## Quantum critical point controlled by applied parallel magnetic field

An exemplarily realization of the superconducting quantum critical point can be obtained by applying the magnetic field parallel to a dirty thin film or a quantum wire.



Electrons that form a Cooper pair pick up different phases due to the presence of the magnetic field  $H$ .



Depairing parameter  $\alpha$  depends on the magnetic field and reflects the strength of the phase breaking effect

$$\alpha = \begin{cases} D(eHd/2c)^2/4 & \text{wire} \\ D(eHt/c)^2/6 & \text{film} \end{cases}$$

$D$  - diffusion coefficient  
 $d$  - diameter of a nanowire  
 $t$  - thickness of the film

## Results: Fluctuation conductivity in the vicinity of the QCP

### 1. Classical regime: $T > \alpha - \alpha_c$

Singular conductivity behavior, similar to the Aslamazov-Larkin correction

$$\delta\sigma_T(\alpha, T) = e^2 \times \begin{cases} \frac{\sqrt{DT}}{4\sqrt{2}(\alpha - \alpha_c)^{3/2}} & \text{wire} \\ \frac{T}{4\pi(\alpha - \alpha_c)} & \text{film} \end{cases}$$

$T$  - temperature

### 2. Intermediate regime:

$$T_0(\alpha) < T < \alpha - \alpha_c$$

$$T \equiv T_0(\alpha) \sim \begin{cases} (\alpha - \alpha_c)^{7/4} / \alpha_c^{3/4} & \text{wire} \\ (\alpha - \alpha_c)^{3/2} / \alpha_c^{1/2} & \text{film} \end{cases}$$

$$\delta\sigma_T(\alpha, T) = e^2 \times \begin{cases} \frac{\pi\sqrt{DT}^2}{12\sqrt{2}(\alpha - \alpha_c)^{5/2}} & \text{wire} \\ \frac{T^2}{18(\alpha - \alpha_c)^2} & \text{film} \end{cases}$$

### 3. Quantum regime:

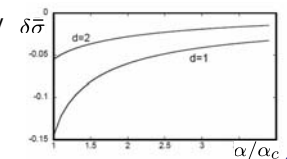
Conductivity is almost temperature independent.

Negative magnetoresistance.

Dimensionless conductivity correction at  $T=0$

$$1d: \quad \delta\sigma = e^2 \sqrt{D/\alpha_c} \delta\bar{\sigma}$$

$$2d: \quad \delta\sigma = e^2 \delta\bar{\sigma}$$

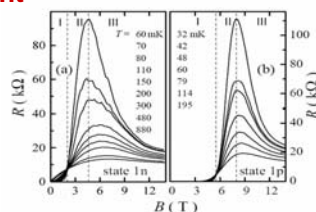
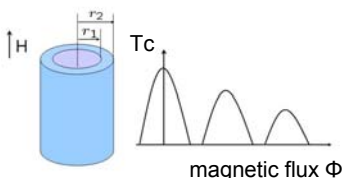


## Experiment

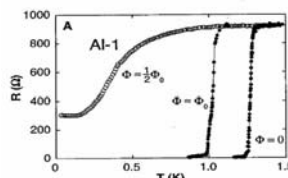
**Films:** Low temperature conductivity of thin films in applied parallel magnetic field exhibits negative magnetoresistance as predicted.

**Quantum wires:**

Thin hollow cylinder in applied magnetic field



Gantmakher VF, et al, JETP Lett. 2000



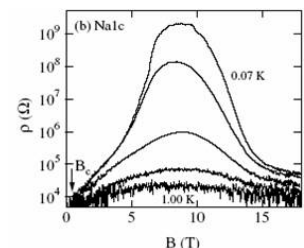
Y. Liu, et al., Science 2001.

## Future directions

1. Theoretical description of experimentally observed superconducting insulator phase in high magnetic fields. This phase is characterized by nonzero local superconducting order parameter but no superconducting coherence. As a result, it has insulating properties.

2. Development of a non perturbative approach for the study of the conductivity behavior close to the quantum Ginzburg region.

3. Study the role of strong disorder in quantum phase transitions.



G. Sambandamurthy et al, PRL 2004

A. V. Lopatin, N. Shah, V.M. Vinokur, Phys. Rev. Lett. 94, 037003 (2005)